Perceptual and Motor Skills, 1995, 80, 1011-1024 © Perceptual and Motor Skills 1995

FOOT AGILITY AND TOE GNOSIS/GRAPHAESTHESIA AS POTENTIAL INDICATORS OF INTEGRITY OF THE MEDIAL CEREBRAL SURFACE: NORMATIVE DATA AND COMPARISON WITH CLINICAL POPULATIONS [1]

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Summary.—A protocol was designed to identify quantitative indicators of the function of the medial surfaces of the cerebral hemispheres. Normative data were collected from 40 volunteers for foot agility, toe gnosis, and toe graphaesthesia. A total of 100 patients (most of whom had been referred for possible closed-head injuries) completed thorough neuropsychological and cognitive assessments. Deficits for toe graphaesthesia were most consistently correlated with general brain impairment and with scores for tasks whose normal performance requires the integrity of structures within the dorsal half of the medial cerebral hemispheres.

Contemporary neuropsychological assessments employ multiple, performance-based measures from which to infer the functional integrity of specific regions within the brain. The validity of such inferences has been supported by strong associations between regional metabolic activity and norm-referenced, quantitative measures of neurocognitive activity (Pawlik & Heiss, 1990; Persinger, 1993a, 1993b).

Measures which are employed to infer the integrity or normal function of the medial surface of the two hemispheres are not traditionally included within neuropsychological batteries (Peters, 1990; Reitan & Wolfson, 1985). According to classic neurological interpretation, dysfunction of the anterior medial surface is associated with motor dysfunction of the lower limbs and with incontinence (Carpenter & Sutin, 1983; Gilandas, Touyz, Beumont, & Greenberg, 1984; Masdeu, 1990). The most common neuropsychiatric correlates are apathy and symptoms which are similar to psychometric depression. Dysfunction within the posterior medial surface affects the sensory domain of the legs and feet, resulting in either hypoaesthesia or paraesthesia (Kolb & Whishaw, 1990; Masdeu, 1990).

The largest portion of the medial surface of the hemispheres is uniquely supplied by the branches of the anterior cerebral artery (Carpenter & Sutin, 1983; Masdeu, 1990). Branches of this artery supply the medial prefrontal

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(including the supplementary motor area) regions, the paracentral (parietal) lobules, and most of the corpus callosum. Although the anterior cerebral artery is normally bilateral, its angioarchitecture is estimated to be asymmetric in about 30% of the population (Carpenter & Sutin, 1983). In these instances the anterior cerebral artery for one of the hemispheres does not emerge from the ipsilateral Middle Cerebral Artery but exits from the contralateral anterior cerebral artery and crosses the longitudinal sulcus. This specific vascular geometry would be vulnerable to shearing and distentional forces which could accompany even mild (but focused) distributions of mechanical energy within the cerebrum.

Clinical or qualitative detection of dysfunction within the medial surface of the hemispheres is usually possible only after catastrophic events such as cerebrovascular failures. Considering the potential vulnerability of this region to the anisotropic distribution of mechanical forces and its intimate involvement with the distal branches of the anterior cerebral artery, we decided to explore the usefulness of employing *quantitative* measurements of foot agility, toe gnosis, and toe graphaesthesia (the analogues of finger agility, gnosis, and graphaesthesia) to help discern neuropsychological impairment.

Method

Subjects

Data for the normative sample were collected from 20 male and 20 female first-year university students. Their mean age was 25 yr. ($SD=7$ yr.); the range was 18 to 50 years. The clinical population involved 100 successive patients who had been referred to us over a 4-yr. period for complete neuropsychological, cognitive, and personality assessments. There were 61 men and 39 women whose mean age was 32 yr. ($SD=13$ yr.); the range was 15 to 60 years. Sixty-one percent of these patients had experienced either (1) CT-verified anomalies or (2) displayed a prolonged (>6 months) syndrome which was consistent with a concussion, contusion, or whiplash brain trauma. The proportions of patients within other categories were 11% epilepsy, 5% stroke, and 3% nonspecific; 20% of the patients had been referred because a neuropsychological basis to adjustment or personality disorders had been strongly suspected. The sinistry, as defined by the procedures of Reitan and Wolfson (1985), was left hand 13%, left foot 11%, and left eye (dominant) 28%.

Procedure

Normative sample.—Each subject was tested individually. Each volunteer in the normative population was administered the finger agility (tapping), finger gnosis, and finger graphaesthesia tasks, according to traditional

(Reitan & Wolfson, 1985) procedures. The total numbers of foot taps per 10 sec. for the highest two out of three (foot) alternating trials were averaged. Each subject was then asked to remove the shoes and socks. Toe gnosis and toe graphaesthesia were measured using procedures very similar to those employed for finger gnosis and graphaesthesia (Richards & Persinger, 1992). For the former, each toe was designated with a number from 1 (large toe) to 5; the total numbers of errors for each foot (four trials for each toe × 5 = maximum of 20 errors per foot) were calculated. Similarly, the numbers 3, 4, 5, and 6 were drawn on the bottom of each toe (four trials per toe × 5; maximum numbers of errors = 20/foot).

Clinical sample.—The patients completed the finger and foot agility, finger and toe gnosis, and finger and toe graphaesthesia tasks. The following measures were also administered: Wechsler Adult Intelligence (Verbal IQ and Performance IQ), Wechsler Memory Quotient (MQ), Peabody Picture Vocabulary Test, Wide Range Achievement Test (Reading, Spelling, and Arithmetic), Trails A, Trails B, Verbal Fluency [numbers of words beginning with F, A, and S per minute each (Gilandas, *et al.*, 1984)], Design Fluency (described by Kolb & Whishaw, 1990, p. 476), Conditioned Spatial Association Test [numbers of blocks (containing numbers of responses for each of six trials) before two successive blocks of no errors plus total numbers of errors before criterion (Milner & Petrides, 1984)], Category Test (number of errors), Grooved Pegboard Test (time in minutes), Rey-Osterrieth (Copy and Memory), Tactual Performance Test (cut-off at 10 min. per hand), Seashore Rhythm Test (number correct), Speech Sounds Test (first 30 items; number correct), Auditory Closure Test (number correct), Sentence Memory Test (number correct), and the modified Damasio and Damasio (50 pairs) Dichotic Word Listening Test (numbers of words correct; Roberts, Varney, Paulsen, & Richardson, 1990). The traditional Halstead-Reitan Impairment Index was calculated.

The means and standard deviations for these tests and procedures for this population of 100 patients are shown in Table 1. The first block of tests

TABLE 1

MEANS AND STANDARD DEVIATIONS FOR INTELLECTUAL, ACHIEVEMENT, MEMORY, AND NEUROPSYCHOLOGICAL MEASURES FOR 100 PATIENTS

Variable	*M*	*SD*
WAIS Verbal	91.2	13.1
WAIS Performance	92.9	14.5
Memory Quotient	95.7	17.4
Receptive Vocabulary	88.9	19.2

(continued on next page)

Note.—The intelligence, memory, and achievement tests are expressed as standardized scores whereas the neuropsychological measures are expressed as raw scores. Scores for the finger and foot tap measures are the mean of both hands or feet.

TABLE 1 (CONT'D)
MEANS AND STANDARD DEVIATIONS FOR INTELLECTUAL, ACHIEVEMENT, MEMORY, AND NEUROPSYCHOLOGICAL MEASURES FOR 100 PATIENTS

Variable	*M*	*SD*
Wide Range Achievement Test		
Reading	98.2	15.3
Spelling	91.9	16.6
Arithmetic	85.8	14.4
Trails A	41.0	19.7
Trails B	106.3	72.5
Verbal Fluency (FAS Words)	39.1	36.1
Design Fluency	19.3	10.0
Conditioned Spatial Association Test		
Block	10.7	4.4
Error	70.0	58.4
Category Test	67.0	31.9
Finger Tapping	46.1	9.8
Foot Tapping	38.7	11.2
PegBoard		
Dominant Hand	74.4	22.5
Nondominant Hand	84.7	50.0
Rey-Osterrieth		
Copy	29.6	4.0
Memory	15.7	7.1
Tactual Performance Test		
Dominant Hand	6.3	2.8
Nondominant Hand	5.5	3.0
Both Hands	3.7	2.6
Memory	6.6	2.0
Location	3.7	2.4
Seashore Rhythm Test	24.6	4.3
Speech Sounds Test	24.4	4.6
Auditory Closure	15.1	6.3
Sentence Memory	15.3	4.5
Dichotic Word Listening		
Left Ear	34.3	10.1
Right Ear	34.6	12.1
Both Ears	25.4	12.9
Halstead-Reitan Impairment Index	0.46	0.28

Note.—The intelligence, memory, and achievement tests are expressed as standardized scores whereas the neuropsychological measures are expressed as raw scores. Scores for the finger and foot tap measures are the mean of both hands or feet.

(Verbal IQ through WRAT-Arithmetic) is expressed as standardized ($M = 100$, $SD = 15$) scores while all of the other values are expressed as raw scores. All analyses involved SPSS software on a VAX 4000 computer.

RESULTS AND DISCUSSION

Normative Data

The means and standard deviations for (1) the mean numbers of finger

taps and foot taps (dominant and nondominant limbs), (2) the total numbers of errors for finger and toe gnosis and graphaesthesia for the right and left limbs, and (3) the absolute discrepancy in scores between the left and right limbs within the normative sample are shown in Table 2 for both men and women. One-way analysis of variance indicated no significant ($p > .05$) difference between the genders.

Zero-order intercorrelations (r) between the agility, agnosia, and graphaesthesia tasks for the feet and hands ranged between .21 and .61. The shared variance (r^2), which was strongest and most consistent between foot agility and finger agility and between toe graphaesthesia and finger graphaesthesia, did not exceed 50%. Although all six of these measures were significantly associated with the Halstead-Reitan Impairment Index, only the correlation with toe graphaesthesia was significantly stronger ($p < .05$ for differences between correlations *coefficients*; see Ferguson, 1959, p. 154) than the coefficients of the other five variables which did not differ significantly from each other. Whereas the zero-order correlations among finger tap, foot tap, finger agnosia, toe agnosia, and finger graphaesthesia and the Impairment Index ranged between 0.40 to 0.43, the magnitude of association with toe number graphaesthesia was 0.61. Consequently, the associations between this measure and the other neuropsychological tests were pursued.

Table 3 shows the zero-order correlations among the intellectual, achievement, and neuropsychological variables and toe and finger (for comparison) graphaesthesia. Partial correlation coefficients after removing the shared variance with the other measure of graphaesthesia (indicated in parentheses) are also shown. After removing the shared variance associated with finger number graphaesthesia, the magnitude of toe number graphaesthesia was still significantly correlated with the impairment for Design Fluency, foot agility, Tactual Performance Test of the dominant hand and both hands, Tactual Performance Test localization, Speech Sounds, Auditory Closure, dichotic word listening for the left ear, right ear, and both ears, and the Halstead-Reitan Index. When the shared variance with toe number graphaesthesia had been first removed, only the scores with the nondominant hand for the pegboard task and the Tactual Performance Test memory score remained uniquely statistically significant.

We decided to (1) examine the utility of using the magnitude of toe graphaesthesia as an index of general and specific brain impairment and (2) check potential nonlinearities which may have masked disproportionate discrepancies between the various tasks and toe number graphaesthesia. The patients were divided into groups according to the numerical distance (z score) from the average score of the normative sample. Table 4 shows the M and SD for various tasks for patients whose toe graphaesthesia scores (total errors for both feet) were between -1 SD of the normative value ($M = 9.1$,

TABLE 2

MEANS AND STANDARD DEVIATIONS FOR DOMINANT AND NONDOMINANT HANDS AND FEET, AND ABSOLUTE RIGHT-LEFT DIFFERENCES ON TASKS OF FINGER- AND FOOT-TAPPING AGNOSIA, AND GRAPHAESTHESIA FOR NORMATIVE SAMPLE

Task	Men, $n = 20$						Women, $n = 20$					
	Dominant Hand		Nondominant Hand		R/L Difference		Dominant Hand		Nondominant Hand		R/L Difference	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Finger Tapping	56.8	7.7	51.8	5.8	5.9	4.7	52.3	4.9	48.5	4.7	5.9	3.2
Finger Agnosia (number of errors)	0.2	0.5	0.5	1.1	0.4	0.7	0.2	0.4	0.3	0.7	0.2	0.7
Finger Graphaesthesia (number of errors)	0.9	1.2	0.5	1.0	0.7	0.9	0.3	0.6	0.1	0.3	0.3	0.6
Foot Tapping	44.2	7.8	44.2	8.1	5.6	5.4	42.6	5.3	39.9	4.7	3.4	3.1
Toe Agnosia (number of errors)	3.2	2.0	4.1	2.2	1.8	1.5	3.7	1.8	4.4	2.1	1.8	1.6
Toe Graphaesthesia (number of errors)	4.3	3.0	3.6	2.2	2.5	1.9	2.9	2.0	3.4	2.9	2.3	1.6
Toe Graphaesthesia (x/o) (number of errors)	0.2	0.4	0.2	0.4	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0

SD = 4.2) and the maximum positive value ($n = 55$) between −1.1 and −2.0 *SD* below the mean ($n = 14$), −2.1 and −3.0 *SD* below the mean ($n = 15$) and lower than −3 *SD* ($n = 16$). Because statistical significance with this magnitude of effect is often not informative, i.e., all variables are significant, the effect sizes as defined by the correlation coefficient *eta* were obtained.

TABLE 3

ZERO-ORDER CORRELATIONS FOR EACH INTELLECTUAL, ACHIEVEMENT, AND NEUROPSYCHOLOGICAL VARIABLE WITH TOE AND FINGER (FOR COMPARISON) GRAPHAESTHESIA FOR 100 PATIENTS. ALSO, PARTIAL CORRELATION COEFFICIENTS AFTER THE SHARED VARIANCE WITH THE OTHER GRAPHAESTHESIA MEASURE HAS BEEN REMOVED ARE SHOWN

Variable	Finger Graphaesthesia	Toe Graphaesthesia	Finger (Toe) Tapping	Toe (Finger) Tapping
WAIS Verbal IQ	−.33	−.36	−.10	−.18
WAIS Performance IQ	−.43	−.45	−.20	−.24
Memory Quotient	−.41	−.34	−.28@	−.13
Receptive Vocabulary	−.32	−.32	−.14	−.13
Wide Range Achievement Test				
Reading	−.14	−.34	.11	−.27@
Spelling	−.09	−.27	.08	−.21
Arithmetic	−.17	−.31	−.09	−.10
Trails A	.52	.49	.30	.31
Trails B	.55	.52	.31	.30
Verbal Learning (FAS Words)	−.04	−.23	−.01	−.15
Design Fluency	−.38	−.54	−.13	−.41@
Conditioned Spatial Association Test				
Blocks	.48	.37	.31	.25
Errors	.48	.38	.32	.25
Category Test	.31	.34	.09	.21
Finger Tapping	−.39	−.37	−.13	−.26
Foot Tapping	−.28	−.32	.03	−.28@
PegBoard				
Dominant Hand	.52	.44	.24	.26
Nondominant Hand	.48	.26	.36@	.03
Rey-Osterrieth				
Copy	−.36	−.36	−.28	−.19
Memory	−.40	−.38	−.35	−.25
Tactual Performance Test				
Dominant Hand	.34	.46	.12	.36@
Nondominant Hand	.45	.50	.32	.34
Both Hands	.38	.52	.11	.41@
Memory	−.48	−.32	−.35@	−.20
Location	−.38	−.50	−.17	−.35@
Seashore Rhythm Test	−.39	−.26	−.26	−.11
Speech Sounds Test	−.43	−.44	−.01	−.40@

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@Indicates a statistically significant association whose variance is not also reflected in that association for the homologous digits (fingers vs toes).

TABLE 3 (CONT'D)
ZERO-ORDER CORRELATIONS FOR EACH INTELLECTUAL, ACHIEVEMENT, AND NEUROPSYCHOLOGICAL VARIABLE WITH TOE AND FINGER (FOR COMPARISON) GRAPHAESTHESIA FOR 100 PATIENTS. ALSO, PARTIAL CORRELATION COEFFICIENTS AFTER THE SHARED VARIANCE WITH THE OTHER GRAPHAESTHESIA MEASURE HAS BEEN REMOVED ARE SHOWN

Variable	Finger Graphaesthesia	Toe Graphaesthesia	Finger (Toe) Tapping	Toe (Finger) Tapping
Auditory Closure	–.35	–.45	.01	–.44@
Sentence Memory	–.34	–.29	–.03	–.23
Dichotic				
Left Ear	–.27	–.43	–.05	–.36@
Right Ear	–.30	–.41	–.09	–.32@
Both Ears	–.32	–.45	–.09	–.36@
Halstead-Reitan Impairment Index	.44	.60	.10	.50@

@Indicates a statistically significant association whose variance is not also reflected in that association for the homologous digits (fingers vs toes).

All group differences, except for the word component of the Stroop, were statistically significant ($F_{3,96}$, $p < .01$). Although the *eta* value for the Performance IQ was not significantly higher ($z < 1.96$) than that for the Verbal IQ, the explained variance accommodated by toe number graphaesthesia for Design Fluency ($eta = 0.57$) was significantly ($z > 1.96$, $p < .05$) greater than that for the Verbal Fluency ($eta = 0.26$). Similarly, the coefficient of determination for the color-word score for the Stroop test was significantly greater than that for the word only (reading) component of this test.

As a final assessment to estimate the similarity between our normative sample (primarily university students) and patients who exhibited minimal brain dysfunction as defined by the Halstead-Reitan Battery, scores for the specific indicators for the normative sample were compared with scores on these indicators for the 39 patients whose individual Impairment Indices were less than or equal to 0.3, i.e., no brain impairment. The results are shown in Table 5. The three largest differences between the patients and the reference group occurred on Trails A, Design Fluency, and finger graphaesthesia. Thus scores on all of the other measures, particularly agility, agnosia, and graphaesthesia for the feet, did not differ significantly between the groups.

The subset or component of a complex system which contains the least redundancy or minimal number of elements is often most sensitive to mild disruptions or insults to the entire system. Compared with fingers and hands, the neuronal representation of the toes and the feet within the cerebrum is either less dense or less integrated. Both normal subjects and nonimpaired patients displayed between four to eight times the numbers of errors for the identification of their digits (agnosia) and for numbers (graphaesthesia) when the toes were stimulated compared to the fingers. Because

TABLE 4

MEANS AND STANDARD DEVIATIONS FOR INTELLECTUAL, MEMORY, ACHIEVEMENT, AND NEUROPSYCHOLOGICAL TASKS BY TOE GRAPHAESTHESIA

Variable	± to 1.0 *SD* *n*, 55		> −1.1 to < −2 *n*, 14		> −2.1 to < −3 *n*, 15		> −3.1 *n*, 16		*eta*
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	
WAIS Verbal	95.0	12.0	92.0	15.0	87.0	13.0	84.0	14.0	.24
WAIS Performance	100.0	13.0	89.0	13.0	85.0	9.0	84.0	15.0	.46
Memory Quotient	101.0	17.0	91.0	14.0	87.0	14.0	91.0	16.0	.34
Receptive Vocabulary	94.0	16.0	93.0	18.0	80.0	20.0	81.0	23.0	.33
Wide Range Achievement Test									
Reading	103.0	13.0	99.0	15.0	93.0	15.0	88.0	19.0	.36
Spelling	96.0	15.0	89.0	15.0	90.0	18.0	83.0	18.0	.29
Arithmetic	90.0	13.0	88.0	14.0	78.0	9.0	77.0	18.0	.38
Trails A	31.5	11.1	50.0	21.2	47.5	21.5	52.8	22.7	.53
Trails B	77.0	40.0	97.0	31.0	121.0	59.0	166.0	97.0	.51
Verbal Fluency (FAS Words)	38.0	11.4	35.1	11.5	30.8	13.2	29.5	10.6	.26
Design Fluency	25.1	9.1	13.5	7.9	13.0	7.6	13.5	6.9	.57
Conditioned Spatial Association Test									
Blocks	9.0	4.3	10.8	4.5	12.8	3.8	13.4	3.3	.40
Errors	45.0	40.0	84.0	69.0	105.0	73.0	106.0	62.0	.46
Category Test	56.0	30.0	60.0	36.0	85.0	28.0	79.0	22.0	.37
Finger Tapping	49.0	6.5	48.0	6.7	46.0	9.8	39.0	7.9	.39
Foot Tapping	42.0	9.6	40.3	11.3	36.5	10.9	32.5	9.6	.32
Pegboard									
Dominant Hand	67.0	18.0	72.0	16.0	74.0	15.0	90.0	21.0	.36
Nondominant Hand	71.0	27.0	112.0	10.0	78.0	23.0	94.0	27.0	.32
Rey-Osterrieth									
Copy	30.9	3.5	29.1	3.3	28.7	3.2	26.5	5.5	.40
Memory	18.2	6.6	14.2	7.4	12.1	6.0	13.2	5.4	.37

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TABLE 4 (CONT'D)
MEANS AND STANDARD DEVIATIONS FOR INTELLECTUAL, MEMORY, ACHIEVEMENT, AND NEUROPSYCHOLOGICAL TASKS BY TOE GRAPHAESTHESIA

Variable	± to 1.0 *SD* *n*, 55		> −1.1 to < −2 *n*, 14		> −2.1 to < −3 *n*, 15		> −3.1 *n*, 16		*eta*
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	
Tactual Performance Test									
Dominant Hand	5.1	2.2	6.7	3.0	7.9	3.1	7.9	2.9	.44
Nondominant Hand	4.2	2.3	6.3	3.3	6.4	3.6	8.0	3.0	.48
Both Hands	2.4	1.4	4.3	2.9	5.5	2.8	5.7	3.0	.55
Memory	7.1	1.6	7.2	1.6	5.4	2.0	5.6	2.3	.40
Location	4.9	2.0	3.3	2.5	2.0	1.8	2.2	2.0	.51
Seashore Rhythm	25.7	3.3	24.6	3.7	21.2	6.7	23.2	4.1	.38
Speech Sounds	26.2	3.1	24.5	3.6	22.7	5.3	20.7	5.5	.47
Auditory Closure	17.2	5.1	16.0	6.3	11.4	6.8	10.7	5.6	.45
Sentence Memory	16.5	3.7	14.4	6.3	14.0	4.1	13.5	4.1	.40
Dichotic Word Listening									
Left Ear	37.5	7.7	35.9	5.5	26.2	12.7	29.5	12.1	.43
Right Ear	38.8	7.8	35.0	15.1	26.3	14.9	29.3	15.0	.40
Both Ears	30.0	10.0	25.1	12.1	15.9	12.7	19.5	14.8	.42
Halstead-Reitan Impairment Index	0.3	0.2	0.5	0.3	0.7	0.2	0.7	0.2	.64
Stroop Word	46.0	10.0	37.0	9.0	40.0	10.0	32.0	10.0	.18
Stroop Color	43.0	9.0	35.0	9.0	33.0	8.0	29.0	7.0	.24
Stroop CW	44.0	7.0	35.0	7.0	36.0	7.0	37.0	8.0	.46
AVLT (tot)	48.0	12.0	41.0	13.0	40.0	14.0	37.0	14.0	.32
Finger Graphaesthesia	2.4	2.4	7.8	6.9	6.3	4.9	10.9	7.5	.55
Toe Graphaesthesia	7.3	3.9	9.1	3.6	9.8	4.7	11.0	3.3	.39
Finger Gnosis	1.2	2.3	2.3	3.9	2.5	3.2	3.5	3.2	.28

graphaesthesia requires both digit (toe) detection and discrimination of tactile/proprioceptive patterns (numbers drawn by a stylus), one would expect that toe graphaesthesia would be particularly sensitive to quantitative indices of brain impairment. Verification of this principle in the present study was indicated by the significant correlation between toe graphaesthesia and the general Halstead-Impairment (HR) Index.

TABLE 5

MEANS AND STANDARD DEVIATIONS FOR NORMATIVE SAMPLE ($N = 40$) VS ALL CLIENTS ($N = 39$) WHOSE HALSTEAD-REITAN IMPAIRMENT INDICES WERE LESS THAN OR EQUAL TO 0.3, I.E., NO BRAIN IMPAIRMENT, AND F RATIOS FOR MAGNITUDE OF DIFFERENCE BETWEEN GROUPS

Variable	Normative Sample		Patients		F
	M	*SD*	*M*	*SD*	
Age, yr.	25	7	26	9	0.27
Trails A, sec.	21.2	6.7	27.7	6.4	20.09‡
Trails B, sec.	53.2	22.5	62.7	17.4	4.59†
Written Fluency (number of s words)	43.8	11.9	38.2	9.5	5.05†
Design Fluency	36.2	14.2	24.6	9.2	17.36‡
Conditioned Spatial Association Test Blocks*	8.6	3.7	7.9	3.7	0.66
Finger Gnosis (Total errors)	0.5	1.1	1.1	2.3	2.17
Finger Graphaesthesia (Total errors)	0.9	1.5	2.8	3.4	10.97‡
Toe Gnosis (Total errors)	7.6	3.3	6.8	4.0	1.05
Toe Graphaesthesia (Total errors)	7.1	4.1	8.2	4.7	0.75
Finger Tapping (*M*)	52.4	5.5	51.0	6.2	1.10
Foot Tapping (*M*)	42.7	5.8	44.0	10.0	0.51

†$p < .05$. ‡$p < .001$. *Number of blocks to criterion.

That this significant association between the Halstead-Reitan Index and toe graphaesthesia was not confounded by the shared variance with the capacity for finger graphaesthesia was indicated by the resilience of this association after the shared variance with the more frequently employed indicator of finger graphaesthesia had been removed. However, the converse was not apparent. When the variance shared between finger graphaesthesia and toe graphaesthesia had been removed, a significant correlation between the failure to identify numbers drawn upon the fingers and general brain impairment was no longer evident.

One of the primary goals of modern neuropsychology is to identify the patterns of regions within brain space which mediate the performance (dynamic sequence) of specific tasks. Optimally, systematic quantitative (although not necessarily linear) relationships should exist between the scaled scores of the psychometric or performance-based task and the amount of activation, metabolic activity, or energy utilization within specific brain regions. Both human and rodent research (Persinger, *et al.*, 1993, 1994) continue to emphasize the multifocal involvement of brain space with appar-

ently simple tasks. We would expect that close scrutiny of "regional" correlations should yield subsets of areas or foci within which subcomponents of what appears to be a homogeneous behavioral task are mediated.

If both the operational characteristics of the task and the magnitude of the correlation were considered, then the specific variance associated with toe graphaesthesia was primarily associated with the middle portion of the medial cerebral surface that is immediately above the portion of the corpus callosum through which temporoparietal fibers intercalate with the adjacent hemisphere (Musiek, 1986). The occurrence of correlations between toe graphaesthesia and scores on tasks which would be associated traditionally with more rostral medial regions, e.g., foot tap, or more caudal regions (reading/decoding) were less frequent and exhibited weaker coefficients. To obtain the latter associations and the correlative deficits for (1) the Tactual Performance Test (for both hands, which is strongly associated with the supplementary motor area), (2) dichotic listening and auditory processing (lateral temporal cortices), and (3) localization memory (parietotemporal cortices) would require extraordinarily large (and incapacitating) regions of the cerebrum if one assumed the involvement of only the lateral (convexity) cortices.

The putative involvement of the medial surface near the corpus callosum through which temporoparietal fibers are mediated supports our hypothesis that the most distal portion of the Anterior Cerebral Artery (which supplies this region of the medial cerebral surface) is particularly vulnerable to the ischemia as well as to the distentional shear/stress forces that accompany or follow even mild traumatic brain injuries. The medial occipital surface, caudal to this region which is supplied primarily by branches of the Posterior Cerebral Artery (PCA), would not be affected in a comparable manner. Because most of our patients had sustained closed-head injuries, the possible amplification of this effect in our results cannot be excluded.

The probability is very small that our normative data were distorted by testing a university population. The results shown in Table 5 indicated that the general proficiency on most tasks for patients who did not exhibit brain impairment [as defined by Halstead-Reitan Index scores of 0.3 or less] was similar to that of the university volunteers. There were no statistically significant differences between patients whose indices were within the "normal" range and university students for the foot-toe (agility, gnosis, and graphaesthesia) and finger (agility, gnosis) measures. The marginal differences between these groups for written fluency (numbers of S words per 5 min.), alteration of set (Trails B) and trials to criteria for the conditioned spatial association task would be commensurate with the type of skills which would be selected by the demands of a university environment.

Of potential interest is the magnitude of the poorer performance on two specific right prefrontal tasks, Trails A and Design Fluency, for the pa-

tients despite their minimal impairment indices. These results suggest that patients who exhibit closed-head injuries (at least in the patients referred to us) may experience detectable right prefrontal anomalies embedded within an otherwise "normal" profile. If this argument is valid, then finger graphaesthesia which has been traditionally associated with anterior cerebral damage (Gilandas, *et al.*, 1984) may also be affected by a significant right prefrontal component.

Possible confounds from other portions of the brain to the direction and magnitude of the relationship between toe graphaesthesia and general neuropsychological impairment are unlikely. Although Peters' (1990) review addresses the role of the anterior cerebellum for the execution of lower limb movement, we did not observe this conspicuous type of ataxia. However, in response to suggestions by referees, we evaluated possible hidden associations between classic indicators of cerebellar dysfunction and the two quantitative indicators (Halstead-Reitan Impairment and toe graphaesthesia) for the patients of this study.

Our protocol during neuropsychological assessments involves the rating of 25 neurological indicators (a 0, 1, 2, or 3 scale to reflect increasing severity) which are employed as inferences for the integrity of most of the cranial nerves and neuromuscular system. The strength of the correlation (Pearson *r*) between the total score for these indicators and the Halstead-Reitan Index (for these 100 patients) was 0.54. The specific correlations (Spearman *rho*) between anomalies of lateral eye pursuit and the standardized measures were for toe agnosia 0.03, toe graphaesthesia 0.27 ($p < .01$), finger agnosia −0.12, finger graphaesthesia 0.03, and the Halstead-Reitan Impairment Index 0.28 ($p < .01$). There were no statistically significant correlations ($p > .05$) between these quantitative measures and the scores for dizziness following rapid, alternating passive pursuit (eye track) or for the Rhomberg (eyes-closed) test.

However, the impairment for rapid alternation of hand position upon the knees (dysdiadochokinesis) was significantly ($p < .01$) associated with toe graphaesthesia ($r = 0.29$) and general impairment ($r = 0.39$) but not with the other measures. After the shared variance between the impairment index and toe graphaesthesia had been removed, the correlation between the latter and the inference of cerebellar function was no longer significant statistically ($r = 0.12$). After the shared variance with toe graphaesthesia was removed, the correlation between the general impairment index and dysdiadochokinesis was still significant ($r = 0.31$, $p < .01$). However, the potential co-involvement or a specific cerebellar contribution to these tasks cannot be excluded totally. This issue may be methodologically relevant since techniques such as single positron emission tomography (SPECT) often employ cerebellar activity as the reference for measurement.

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Accepted March 31, 1995.